LiDAR Mapping Project Report
South Carolina - Clarendon
February 13, 2009

Submitted to:
USGS
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EXECUTIVE SUMMARY

Reference: USGS Contract 07CRCN0004, Task Order 07004C0009, South Carolina 16 County LiDAR, dated January 17, 2008.

This report documents Dewberry's actions to quality assure the LiDAR deliverables of Clarendon County, SC, produced by Dewberry's subcontractor, Fugro EarthData, under the referenced USGS task order. The LiDAR data was acquired in January of 2008 and delivered as LiDAR LAS point cloud data in five ASPRS LAS classes (class 1 = non-ground; class 2 = ground; class 8 = intelligently-thinned model key points; class 9 = water; and class 12 = overlap points not used in other classes). The LiDAR data was determined to be of high quality.

Completeness: Dewberry verified the completeness of the classified LiDAR points, intensity images, and an ESRI geodatabase containing a terrain (triangulated irregular network) and ground masspoints. Hydrographic breaklines were delivered separately by watershed. Dewberry verified that the high density masspoint data has an average point spacing less than 1.4m, that 504 tiles (each 5000 ft x 5000 ft) were delivered covering all of Cherokee County, that all data was delivered in the correct file format and projected to the South Carolina State Plane Coordinate System in International feet, NAD83 HARN, with elevations in meters, NAVD88; and that the FGDC-complaint metadata satisfies project requirements.

Quantitative: Using checkpoints surveyed by the South Carolina Geodetic Survey, Dewberry tested the RMSEz, Fundamental Vertical Accuracy (FVA) in open terrain, Consolidated Vertical Accuracy (CVA) in all land cover categories, and Supplemental Vertical Accuracy (SVA) in each of three major land cover categories per FEMA requirements, and the accuracy easily surpassed the specified accuracy required, as shown below, when tested per FEMA, NSSDA, NDEP and ASPRS guidelines.

Criterion	Checkpoints Required	Checkpoints Used	Accuracy Specification	Results Achieved
RMSEz	60	78	18.5 cm	7.4 cm
FVA	20	21	36.3 cm	17.8 cm
CVA	60	78	36.3 cm	13.6 cm
SVA-bare earth	20	21	36.3 cm	13.8 cm
SVA-vegetated	20	32	36.3 cm	8.7 cm
SVA-urban	20	25	36.3 cm	14.5 cm

Qualitative: Dewberry visually inspected 100% of the data; no remote-sensing data voids were found and the data is free of major systematic errors. The cleanliness of the bare earth model meets expectations; minor errors were found in less than 2% of the data, including poor LiDAR penetration, small misclassifications, and inconsistent editing. Two anomalies not affecting DEM accuracy or usability were found in the intensity images, including white stripes over land at nadir and tonally dark areas in some flight lines. All of the deliverables extend to the county boundaries where adjoining counties are not delivered; where adjoining counties are delivered there is no clipping of the tiles.

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QA REPORT

1 Introduction

The following definitions are provided to distinguish between steps taken by Dewberry, as prime contractor, to provide Quality Assurance (QA) of the LiDAR data produced by Fugro EarthData, and steps taken by Fugro EarthData, as data producer, to perform Quality Control (QC) of the data that it provides to Dewberry. Collectively, this QA/QC process ensures that the LiDAR data delivered to USGS and its client (South Carolina Department of Natural Resources) are accurate, usable, and in conformance with the deliverables specified in the Scope of Work. These definitions are taken from the DEM Quality Assessment chapter of the 2nd edition of "Digital Elevation Model Technologies and Applications: The DEM Users Manual," published by the American Society for Photogrammetry and Remote Sensing (ASPRS), 2007:

> **Quality Assurance (QA)** — Steps taken: (1) to ensure the end client receives the quality products it pays for, consistent with the Scope of Work, and/or (2) to ensure an organization's Quality Program works effectively. Quality Programs include quality control procedures for specific products as well as overall Quality Plans that typically mandate an organization's communication procedures, document and data control procedures, quality audit procedures, and training programs necessary for delivery of quality products and services.
>
> **Quality Control (QC)** — Steps taken by data producers to ensure delivery of products that satisfy standards, guidelines and specifications identified in the Scope of Work. These steps typically include production flow charts with built-in procedures to ensure quality at each step of the work flow, in-process quality reviews, and/or final quality inspections prior to delivery of products to a client.

Dewberry's role is to provide overall project management as well as quality management that include QA of the data including a completeness validation of the LiDAR masspoints, vertical accuracy assessment and reporting, and a qualitative review of the derived bare earth surface. In addition, Dewberry provides an extensive review of other derived products such as 3D streamlines, TIN-terrain, and LiDAR intensity images.

First, the completeness verification is conducted at a project scale (files are considered as the entities) for all products. It consists of a file inventory and a validation of conformity to format, projection, and georeference specifications. At this point Dewberry also ensures that the data adequately covers the project area for all products. The LiDAR data review begins with the computation of general statistics over all fields per file, followed by an analysis of the results to identify anomalies, especially in the elevation fields and LAS class fields.

The quantitative analysis addresses the quality of the data based on absolute accuracy of a limited collection of discrete checkpoint survey measurements. Although only a small amount of points are actually tested through the quantitative assessment, there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to surrounding LiDAR measurements as acquisition conditions remain similar from one point to the next.

To fully address the LiDAR data for overall accuracy and quality, a manual qualitative review for anomalies and artifacts is conducted on each tile. This includes creating pseudo-image products such as 3-dimensional models. The QA analyst uses multiple images and overlays to find potential errors in the data as well as areas where the data meets and exceeds expectations.

Three fundamental questions are addressed during Dewberry's QA process:

- Is the data complete?
- Did the LiDAR system perform to specifications?
- Did the ground classification process yield desirable results for the intended bare-earth terrain product?

Under the referenced task order, LiDAR data was acquired for 16 counties in South Carolina (**Figure 1**). This report focuses on the deliverables covering Orangeburg County that are directly derived from the LiDAR. The hydro-lines, derived from the LiDAR, are being delivered per watershed and thus will be discussed in a subsequent report. All quality assurance processes and results are given in the following sections.

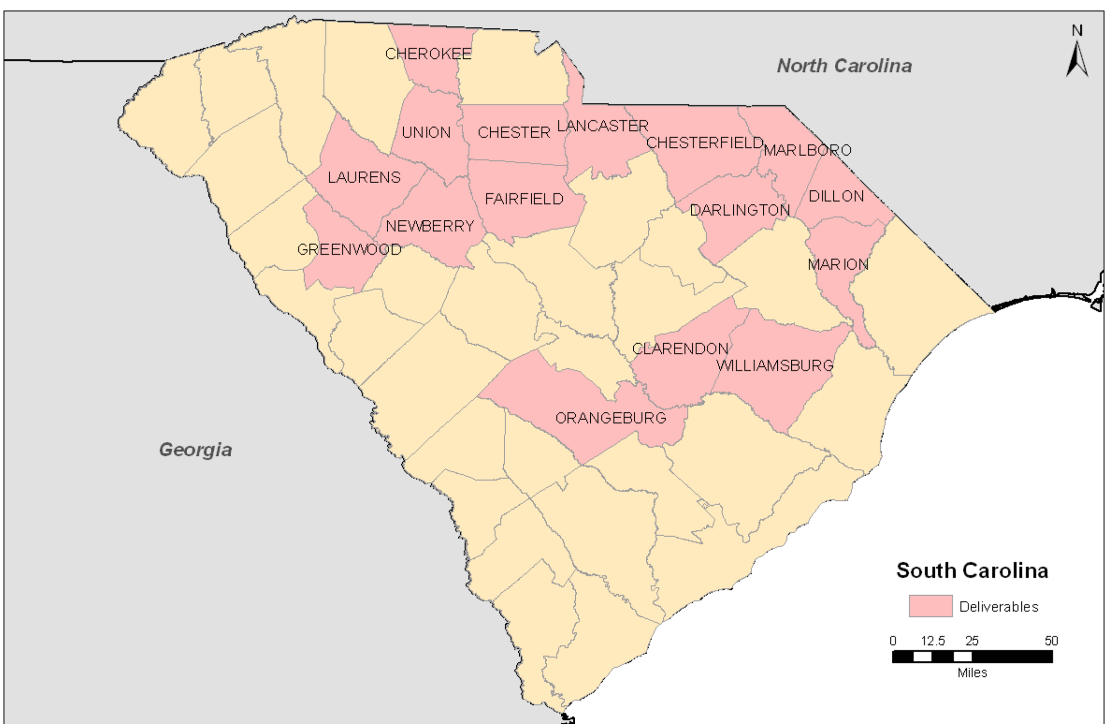

Figure 1 *– Project area; Deliverable Counties shown in pink.*

2 Completeness of deliverables

Dewberry reviews the inventory of the data delivered by validating the format, projection and georeferencing. County based deliverables are listed in Table 1.

Table 1 - County deliverables.

Dataset	Format	Spatial
LiDAR	LAS	Tiled
Intensity images	GeoTiff	Tiled
Terrain (bare earth)	ESRI feature class Terrain	1 feature class
Ground masspoints	ESRI feature class multipoints	1 feature class
Boundary	ESRI geodatabase feature class - polygons	3 feature classes (county/tile/LiDAR)

Clipping of the data along the county boundary was performed according to the following rules (Figure 2):

- a partial tile is delivered at the boundary with a county that is not part of the project,
- a full tile is delivered at the boundary with a county that is part of the project

LAS files and intensity images were delivered in tiles that adhere to these rules and to the State of South Carolina's 5000 ft x 5000 ft tile schema (see Figure 3). The LAS, the ground masspoint feature class, the terrain, and the intensity images extend outside the project boundary with a 50 ft buffer (Figure 4 and Figure 5) as expected.

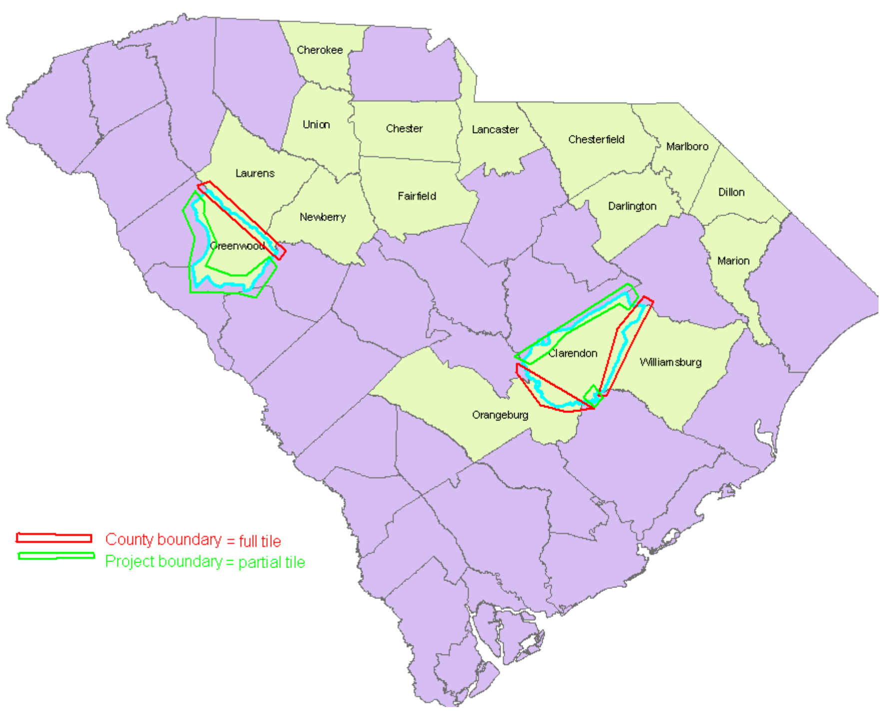

***Figure 2** – Convention used for the tile coverage: at the boundary of a county that is not part of the project, a partial tile is delivered; at the boundary of a county that is part of the project, a full tile is delivered.*

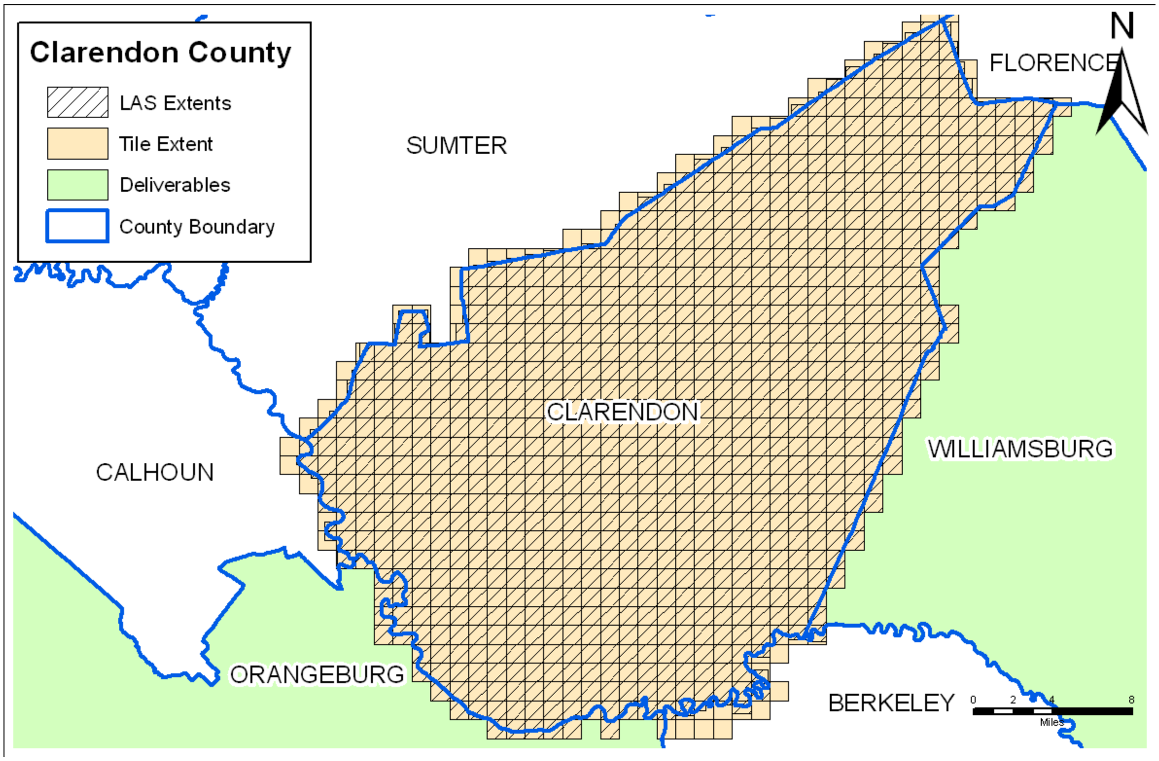

Figure 3 *– The LiDAR coverage of Clarendon County. Neighboring deliverable counties are shown in green.*

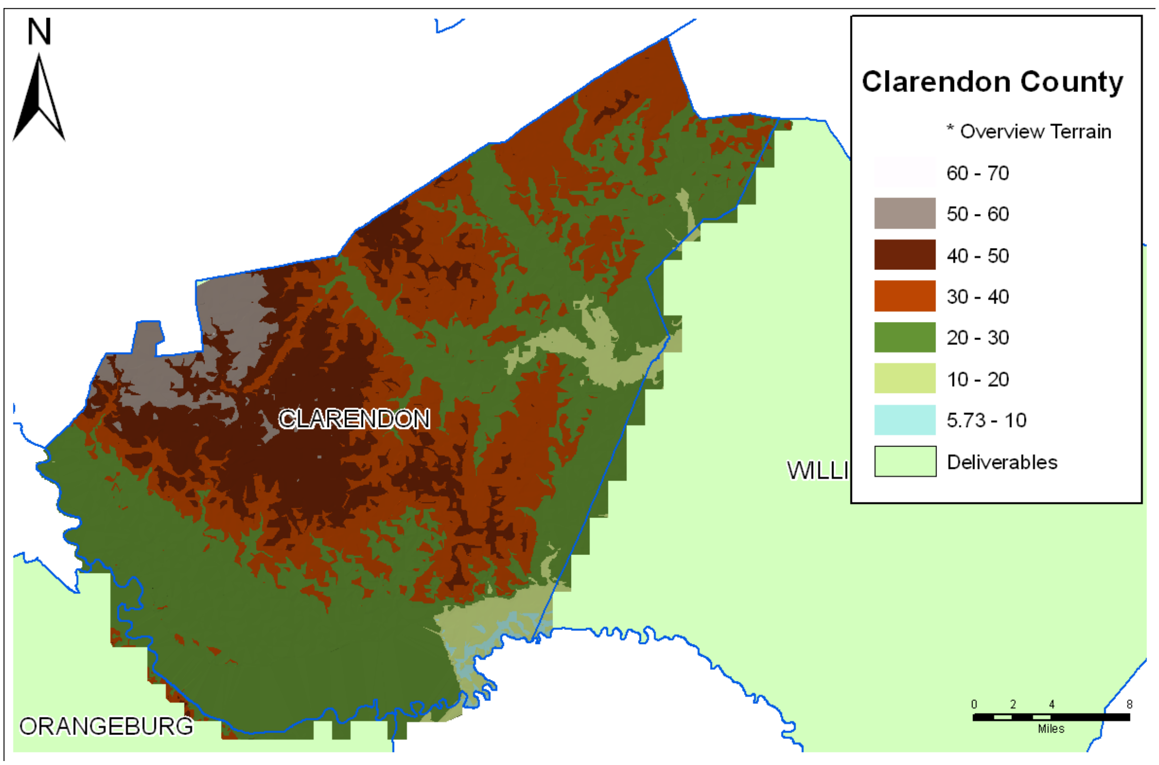

Figure 4 *– The terrain for Clarendon has a 50 ft buffer outside of the project boundary.*

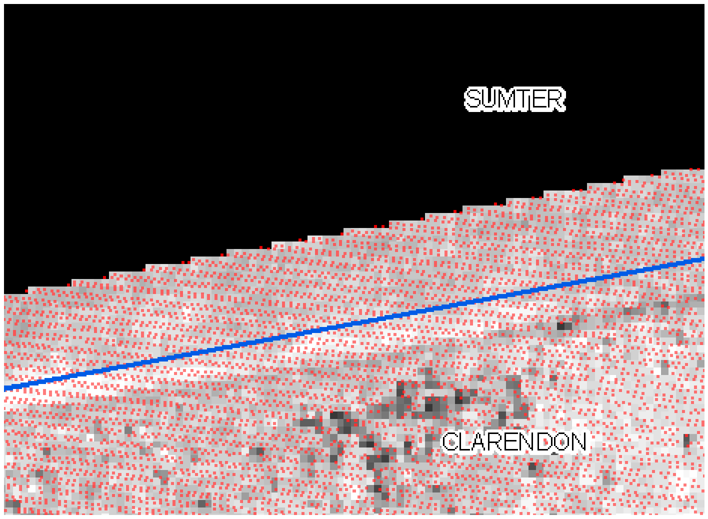

Figure 5 *- Ground masspoints (red) and intensity images extend 50 feet outside the project boundary in yellow. The LAS and terrain do the same. Hydro-lines are clipped at the project boundary and the watershed boundary.*

3 QA of intensity Images

857 intensity images in GeoTiff format were delivered for Clarendon County. An automated script was used to validate that intensity values are integers ranging between 0 and 255, that the cell size is 4ft and that the column and row count is 1250. 1250 multiplied by 4 (the pixel size in ft) equals 5000 which is the required size of the tiles: 5000 ft x 5000 ft. Another automated script was used to validate the header information on all of the GeoTiffs. There were no issues with these checks. An example of the header is shown in Table 2.

Table 2 – Intensity header.

```
File Name: 1598-03.tif
File Information:
 Standard : : TIFF File
 Format : : Byte integers (8 bits)
 Pixels per Line :  1250
 Number of Lines :  1250
 Samples per pixel :  1
 File bits per sample : 8
 Actual bits per sample : 8
 Untiled file
 Number of overviews :  0
 Scanning device resolution :  72  : lines/inch
 Orientation :  4  : Row major order, origin at top left

 NO scan line headers : non-scannable file
 Packet size (16-bit words) : 0
 Free vlt space (16-bit words) : 2000000000
 Free packet space (16-bit words) : 2000000000
Raster to UOR matrix:
 Unspecified or All Zero Matrix
Raster to World Matrix:
 Units: Feet
 amx[ 0]=          4, amx[ 1]=          0, amx[ 2]=
2190000
 amx[ 3]=          0, amx[ 4]=         -4, amx[ 5]=

      0        0        0
      2190000     585000      0
    ModelPixelScaleTag (1,3):
      4        4        0
    End_Of_Tags.
  Keyed_Information:
    GTModelTypeGeoKey (Short,1): ModelTypeProjected
    GTRasterTypeGeoKey (Short,1): RasterPixelIsArea
    ProjectedCSTypeGeoKey (Short,1): Unknown-3361
    ProjLinearUnitsGeoKey (Short,1): Linear_Foot
    End_Of_Keys.
  End_Of_Geotiff.
PCS = 3361 (NAD83(HARN) / South Carolina (ft))
Projection = 15355 (SPCS83 South Carolina zone (International
feet))
Projection Method: CT_LambertConfConic_2SP
  ProjFalseOriginLatGeoKey: 31.833333 ( 31d50' 0.00"N)
  ProjFalseOriginLongGeoKey: -81.000000 ( 81d 0' 0.00"W)
  ProjStdParallel1GeoKey: 34.833333 ( 34d50' 0.00"N)
  ProjStdParallel2GeoKey: 32.500000 ( 32d30' 0.00"N)
  ProjFalseEastingGeoKey: 609600.000000 m
  ProjFalseNorthingGeoKey: 0.000000 m

GCS: 4152/NAD83(HARN)
Datum: 6152/NAD83 (High Accuracy Regional Network)
```

585000	
2190000 , 585000	Ellipsoid: 7019/GRS 1980 (6378137.00,6356752.31)
2195000 , 585000	Prime Meridian: 8901/Greenwich (0.000000/ 0d 0' 0.00"E)
2195000 , 580000	Projection Linear Units: 9002/foot (0.304800m)
2190000 , 580000	Corner Coordinates:
Geotiff_Information:	Upper Left (2190000.000, 585000.000)
Version: 1	Lower Left (2190000.000, 580000.000)
Key_Revision: 1.0	Upper Right (2195000.000, 585000.000)
Tagged_Information:	Lower Right (2195000.000, 580000.000)
	Center (2192500.000, 582500.000)Output from Display
ModelTiepointTag (2,3):	Header

Dewberry also visually checked the tile matching in ArcMap. Overall, the intensity is consistent between adjacent tiles. Tiles over the boundary between two delivered counties are delivered in full for each county. Tiles over the outside project boundary are partial; the section outside the buffered project area is filled with black pixels (value 0).

There was one issue that was found in several tiles in Clarendon County. **Figure 6** is an example of the error. The white stripes occur when the intensity becomes saturated at nadir. Dewberry does not believe that this constitutes a complete failure of the data; however Fugro EarthData has been asked to review this issue. Overall, the intensity images meet specifications and are correctly derived from the LiDAR points.

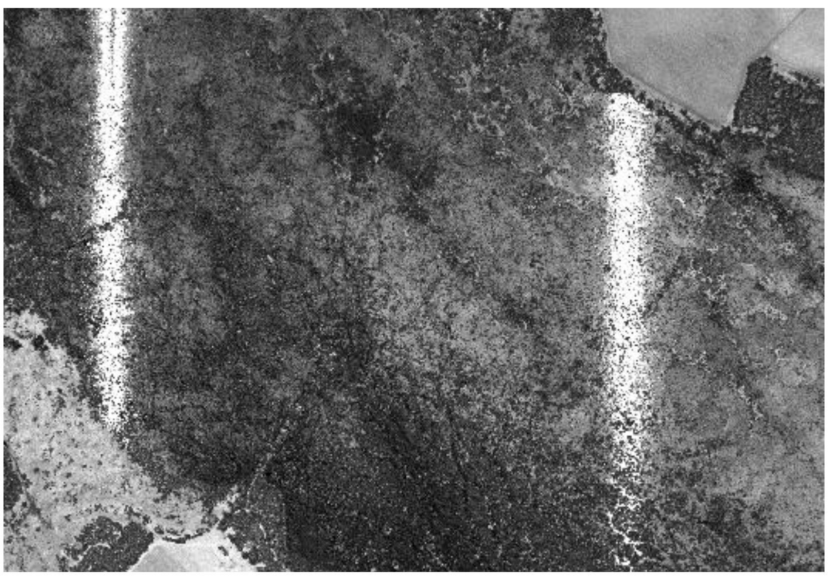

***Figure 6** – Intensity Images with saturated stripes.*

4 Metadata

Dewberry verified the metadata and all of the xml files were FGDC complaint. Metadata is delivered for the project, terrain, intensity images, and the LAS.

5 LiDAR QA

5.1 *Completeness*

5.1.1 LAS inventory

Dewberry received 857 LiDAR files covering the Clarendon County area. The point spacing matches the requirement of an average point spacing of 1.4 meters. They are in the correct format and projection:

- LAS version: 1.1
- Point data format: 1
- Projection set in the header:
  - NAD_1983_HARN_StatePlane_South_Carolina_FIPS_3900_Feet_Intl;
  - Horizontal unit: linear feet;
  - NAVD88 - Geoid03;
  - Vertical unit: meters.

The point spacing matches the requirement of an average point spacing of 1.4 meters.

Each record includes the following fields:

- XYZ coordinates
- Flight line
- Intensity
- Return number, number of return, scan direction, edge of a flight line and scan angle
- Classification:
  - class 1 for non-ground,
  - class 2 for ground (must be combined with class 8 to be complete),
  - class 8 for model key points,
  - class 9 for water,
  - class 12 for overlap
- GPS time (this is expressed in second of the week; note that the date of collection will be given in the metadata file because the date contained in the LAS header is the file creation date according to LAS standard)

5.1.2 Statistical analysis of LAS tile content

To verify the content of the data and to validate the data integrity, a statistical analysis was performed on all the data. This process allows us to statistically review 100% of the data to identify any gross outliers. This statistical analysis consists of:

1. Extract the header information
2. Read the actual records and compute the number of points, minimum, maximum and mean elevation for each class. Minimum and maximum for other relevant variables are also evaluated.

Each tile was queried to extract the number of LiDAR points. With a nominal point spacing of 1.4m, the number of point per tile should be around 3.9 million. The mean over Clarendon is around 4.8 million which proves that the average density is more than what is required and all tiles are within the anticipated size range except for where fewer points are expected (near the external project boundary where tiles are clipped or over large rivers and lakes) as illustrated in Figure 7.

To first identify incorrect elevations, the z-minimum and z-maximum values for the ground class were reviewed. With maximum values between 12 and 61m, no noticeable anomalies were identified because this is consistent with the expected range of elevation in the county (max elevation in Clarendon county: around 60m). Figure 8 (right) shows the spatial distribution of these elevations, following the anticipated terrain topography. Lower elevations are found near hydrographic features; see **Figure 8** (left) for the Z min elevations.

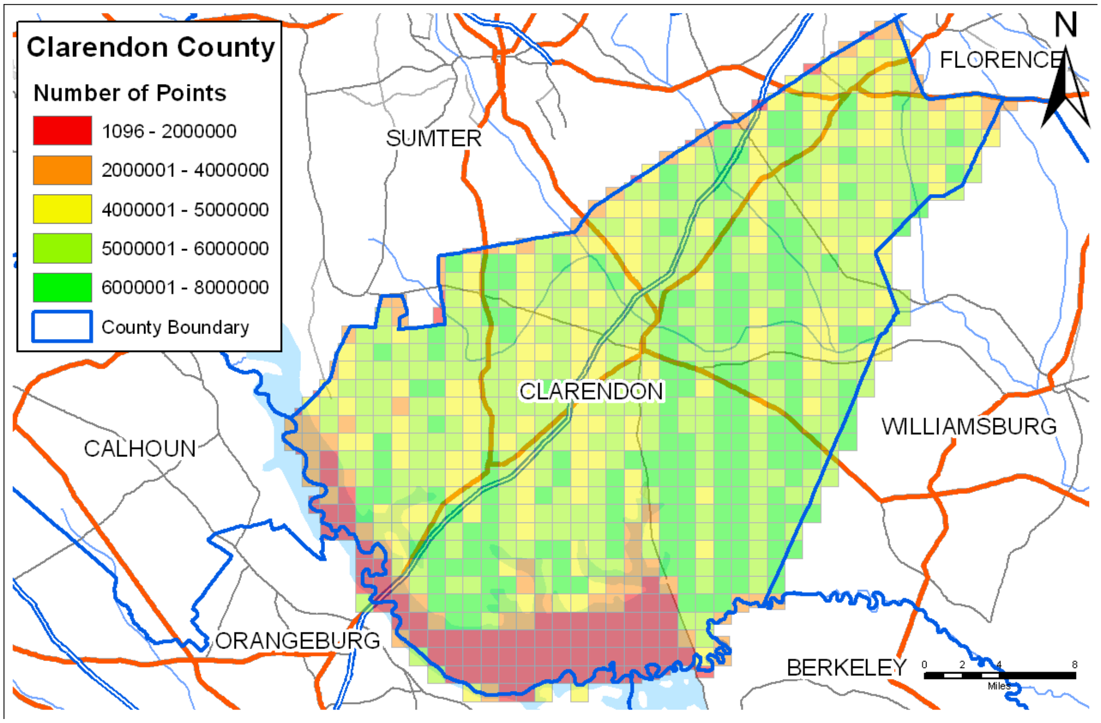

Figure 7 *– Number of points per tile. The red tiles at the border are expected to have fewer points.*

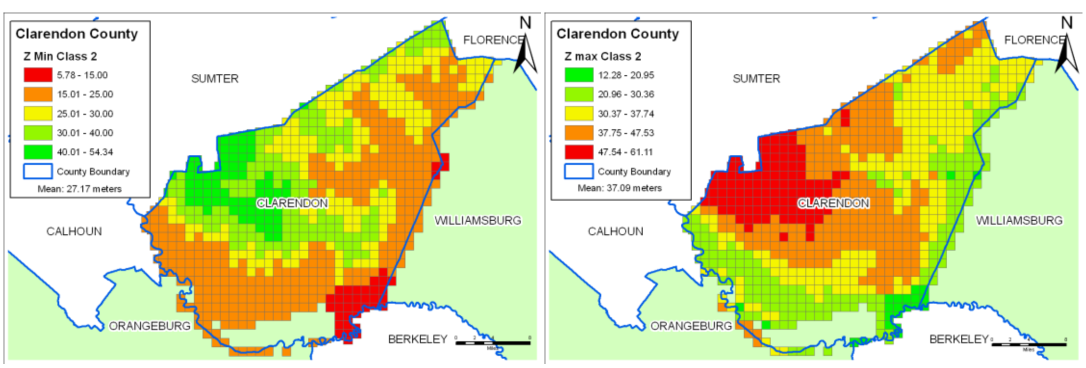

Figure 8 *– Z min and Z max (Class 2). Tiles without ground points are not represented.*

LiDAR Quantitative assessment

5.1.3 Checkpoint inventory

Typically for this type of data collection, a ground truth survey is conducted following the *FEMA Guidelines and Specifications for Flood Hazard Mapping Partners Appendix A: Guidance for Aerial mapping and Surveying* which is based on the NSSDA. This methodology collects a minimum of 20 points for each of the predominant land cover types (i.e. bare-earth, weeds and crop, forest, urban etc.) for a minimum of three land cover classes. By verifying the data in these different classes, the data accuracy is tested, but it also tests whether the classification of the LiDAR has been performed correctly at those test point locations. In this project the predominant land covers selected are bare-earth, mixed vegetation, and urban.

The field survey was conducted and prepared by the South Carolina Geodetic Survey in April 2008. The guidelines were to collect 60 checkpoints in 3 different land covers: 20 points in Urban Areas, 20 points in Open Terrain, and 20 points divided equally in Medium Vegetation and Forested Areas.

In reality 78 points were collected, as presented in Table 3 including an additional class (bush). All the checkpoints used for the vertical assessment of the LiDAR data are available in Appendix A. Figure **9** shows the distribution of the checkpoints throughout the area. The points are grouped together in clusters. In some cases the checkpoints within a zone are less than 100 ft apart which is not ideal but still acceptable.

Table 3 - Number of points required and acquired.

Class	Guidelines	Acquired
o - Open Terrain	20	21
b - Bush	0	10
h - High Grass	10	13
w - Woods	10	9
u - Urban	20	25
Total	**60**	**78**

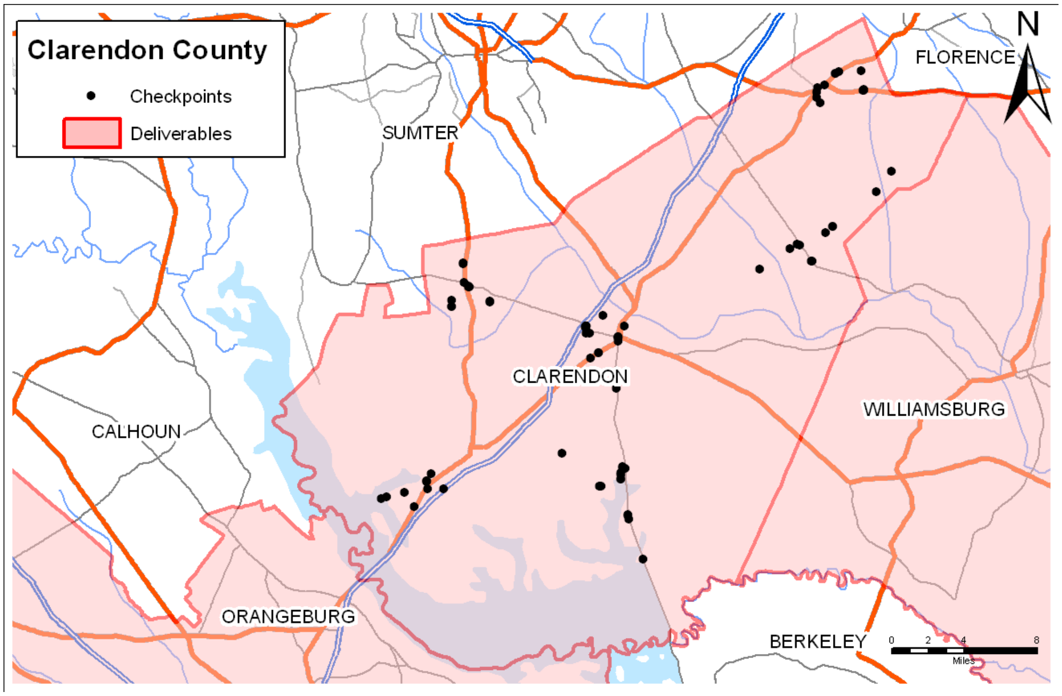

Figure 9 *– Survey checkpoints from South Carolina Geodetic Survey.*

5.1.4 Vertical Accuracy Assessment Methodologies

The first method of testing vertical accuracy used the FEMA specifications which follows the National Standard for Spatial Data Accuracy (NSSDA) procedures. The accuracy is reported at the 95% confidence level using the Root Mean Square Error (RMSE) which is valid when errors follow a normal distribution. By this method, vertical accuracy at the 95% confidence level equals RMSEz x 1.9600. This methodology measures the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The vertical accuracy assessment compares the measured survey checkpoint elevations with those of the TIN as generated from the bare-earth LiDAR. The X/Y locations of the survey checkpoints are overlaid on the TIN and the interpolated Z values are recorded. This interpolated Z values are then compared with the survey checkpoint Z values and this difference represents the amount of error between the measurements.

The second method of testing vertical accuracy, endorsed by the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) uses the same method in open terrain only; an alternative method uses the 95th percentile to report vertical accuracy in each of the other land cover categories (defined as Supplemental Vertical Accuracy – SVA) and all land cover categories combined (defined as Consolidated Vertical Accuracy – CVA). The 95th percentile method is used when vertical errors may not follow a normal error distribution, as in vegetated terrain.

The Fundamental Vertical Accuracy (FVA) is the same for both methods; both methods utilize RMSE x 1.9600 in open terrain where there is no reason for LiDAR errors to depart from a normal error distribution

The following tables and graphs outline the vertical accuracy and the statistics of the associated errors as computed by different methods.

Table 4 shows the complete results of the Clarendon data set run through the FEMA/NSSDA process; vertical accuracy at the 95% confidence level equals the RMSE x 1.9600. By this method, the consolidated vertical accuracy equals the RMSE (0.074 m) x 1.9600, or 0.145 m (14.5 cm).

Table 4 - Final statistics for Clarendon County using FEMA/NSSDA processes.

100 % of Totals	RMSE (m) Spec=0.185m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.074	-0.030	-0.033	-0.151	0.068	78	-0.258	0.148
Bare Earth	0.091	-0.056	-0.054	-0.438	0.074	21	-0.258	0.113
Vegetated	0.054	-0.008	-0.018	0.452	0.054	32	-0.087	0.116
Urban	0.082	-0.037	-0.039	0.284	0.074	25	-0.203	0.148

Table 5 shows the complete results of the Clarendon data set run through the NDEP/ASPRS process; the CVA value is 0.136 m (13.6 cm). The similar results between the two methods (14.5 cm and 13.6 cm) demonstrate that the errors did approximate a normal error distribution, even in vegetation. All of the calculated statistics for Clarendon County fall well below the specifications.

Table 5 - Final statistics for Clarendon County using NDEP/ASPRS processes.

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=36.3 cm	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=36.3 cm	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=36.3 cm
Consolidated	78		13.6 cm	
Bare Earth	21	17.8 cm		13.8 cm
Vegetated	32			8.7 cm
Urban	25			14.5 cm

Error! Reference source not found. illustrates the distribution of the elevation differences between the LiDAR data and the surveyed checkpoints. The errors seem to be slightly concentrated on the negative side (LiDAR lower than the checkpoints) pointing toward a small negative bias in the data.

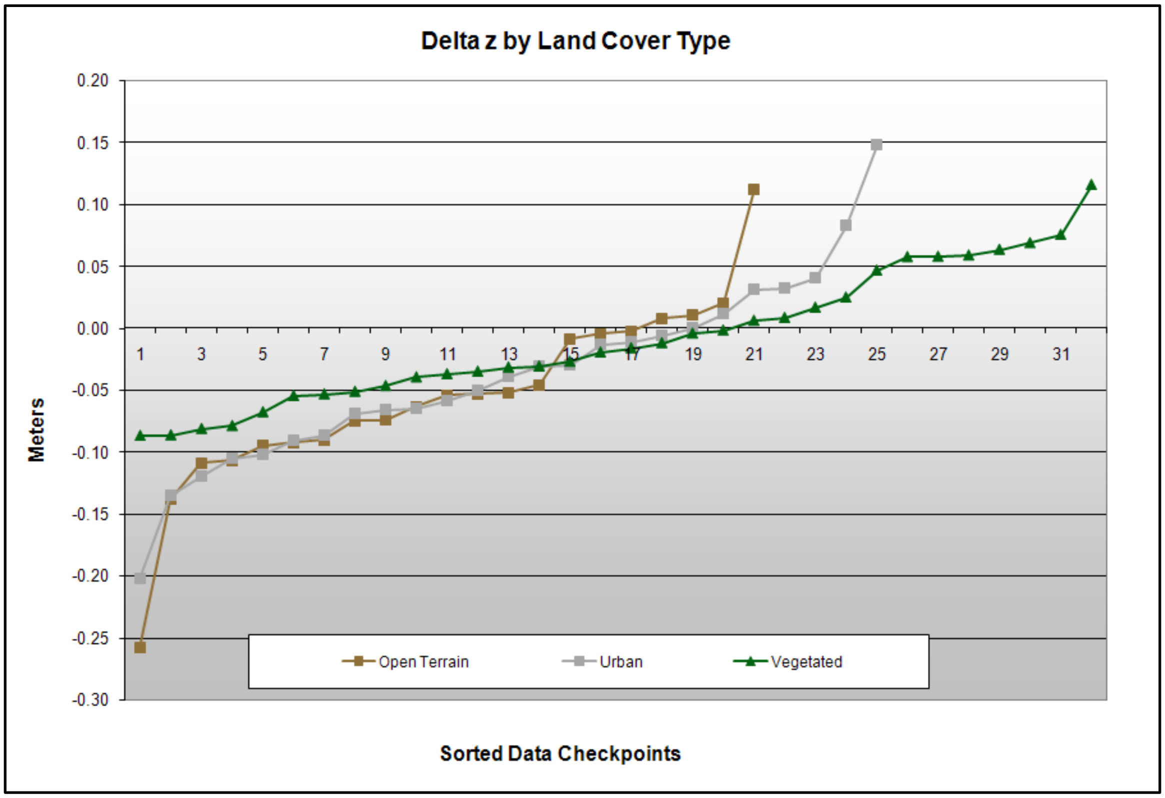

Figure 10 *- Checkpoints shown per land cover type and sorted by errors (deltaZ).*

Given the good results and the high number of checkpoints used, Dewberry is confident that the data meets the accuracy requirements.

Compared with the 36.3 cm specification for vertical accuracy at the 95% confidence level, equivalent to 2-foot contours, the dataset passes by all methods of accuracy assessment:

- Tested 17.8 cm Fundamental Vertical Accuracy at 95% confidence level in open terrain using RMSEz x 1.9600 (FEMA/NSSDA and NDEP/ASPRS methodologies).
- Tested 14.5 cm Consolidated Vertical Accuracy at 95% confidence level in all land cover categories combined using RMSEz x 1.9600 (FEMA/NSSDA methodology).
- Tested 13.6 cm Consolidated Vertical Accuracy at 95th percentile in all land cover categories combined (NDEP/ASPRS methodology).

5.2 *LiDAR Qualitative Assessment*

5.2.1 Protocol

The goal of Dewberry's qualitative review is to assess the continuity and the level of cleanliness of the bare earth product. Each LiDAR tile is expected to meet the following acceptance criteria:

➢ The point density is homogeneous and sufficient to meet the user needs.

- The ground points have been correctly classified (no manmade structures and vegetation remains, no gap except over water bodies);
- The ground surface model exhibits a correct definition (no aggressive classification, no over-smoothing, no inconsistency in the post-processing);
- No obvious anomalies due to sensor malfunction or systematic processing artifact is present (data holidays, spikes, divots, ridges between tiles, cornrows…);
- 90% or more of the artifacts have been removed, 95% of the outliers, 95% of the vegetation, and 98% of the buildings.

Dewberry analysts, experienced in evaluating LIDAR data, performed a visual inspection of the bare-earth digital elevation model (bare-earth DEM). LiDAR masspoints were first gridded with a grid distance of 2x the full point cloud resolution. Then, a triangulated irregular network (TIN) was built based on this gridded DEM and displayed as a 3D surface. A shaded relief effect was applied which enhances 3D rendering. The software used for visualization allows the user to navigate, zoom and rotate models and to display elevation information with an adaptive color coding in order to better identify anomalies.

One of the variables established when creating the models is the threshold for missing data. For each individual triangle, the point density information is stored; if it meets the threshold, the corresponding surface will be displayed in green, if not it will be displayed in red (see Figure 11). It should also be noted that if this density model is created with the ground points only, it is expected to have void areas where buildings exist or in water; vegetation can also reduce the number of points hitting the ground, resulting in more distanced points.

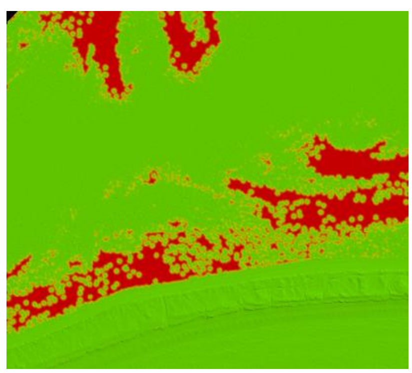

Figure 11 *- Ground model with density information (red means sparse data).*

The first step of Dewberry's qualitative workflow was to verify the point distribution by systematically loading a percentage of the tiles as masspoints colored by flight line (Figure 12) or by class (Figure 13**Error! Reference source not found.**). This particular type of display helps us visualize and better understand the scan pattern, the flight line orientation, flight coverage, and gives additional confirmation that all classes are present and seem to logically represent the terrain.

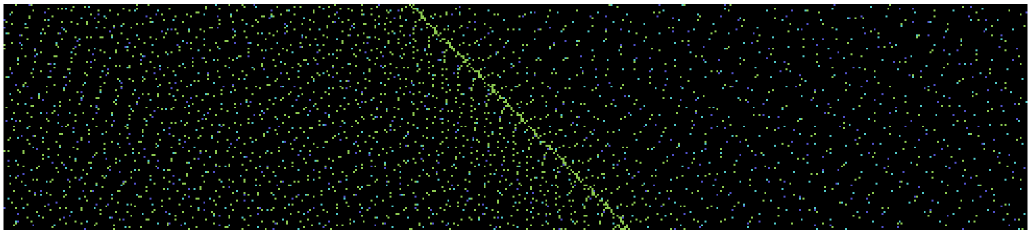

Figure 12 *- LiDAR points colored by flight line. Detail of the point distribution.*

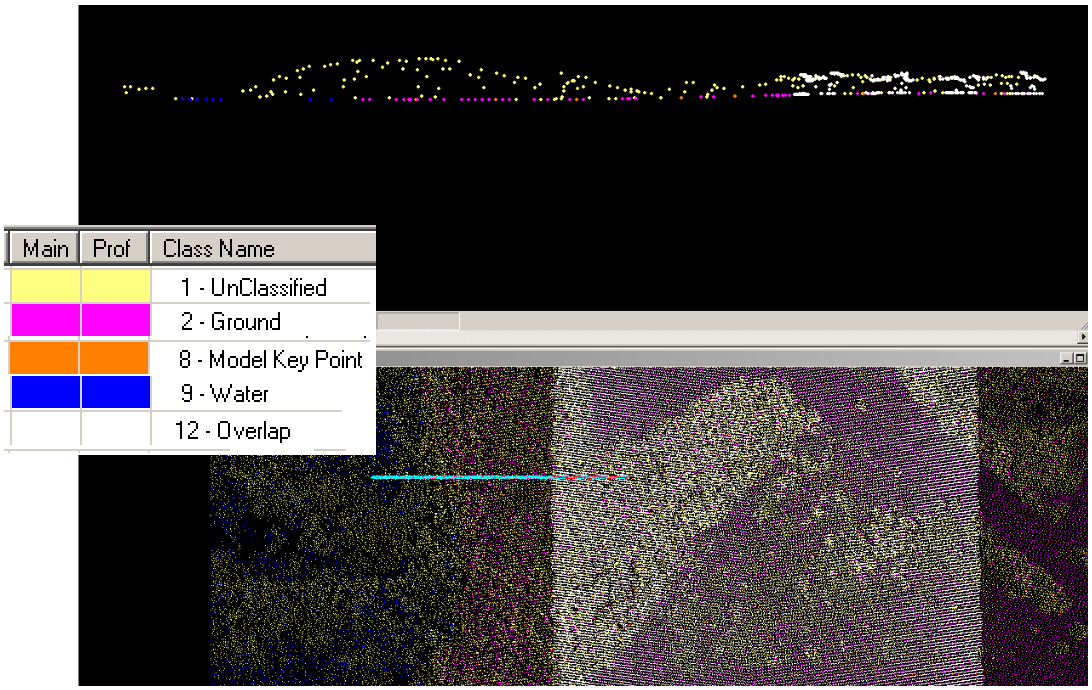

Figure 13 *- Full point cloud colored by classification.*

The second step was to verify data completeness and continuity using the bare-earth DEM with density information, displayed at a macro level. If, during this macro review of the ground models, potential artifacts or large voids are found, we use the digital surface model (DSM) based on the full point cloud including vegetation and buildings will be used to pinpoint the extent and the cause of the issue. Moreover, the intensity information stored in the LiDAR data can be visualized over this surface model, helping in interpretation of the terrain. Finally, if the analyst suspects a systematic error relating to data collection, a visualization of the 3D raw masspoints is performed, rather than visualizing as a surface.

Dewberry's micro-level qualitative review is the process of importing, comparing and analyzing these two later types of models (DSM with intensity and raw masspoint), along with cross section extraction, surface measurements, and density evaluation.

5.2.2 Quality report

Dewberry's qualitative review consists of a micro visual inspection of all the tiles. There is no automated toolset more effective than the manual inspection by a GIS analyst to find errors in automated processing of LiDAR data. The analyst will inspect the data for processing anomalies, classification errors, and full point cloud artifacts remaining in the ground surface models.

After closely examining the dataset, the bare earth model is determined to be of high quality. (**Figure 14**) Dewberry found a few minor errors in the data as outlined in the text and images below. The majority of the calls are due to minor artifacts, misclassifications and poor LiDAR penetration. However, these issues are not serious enough to render the data unusable.

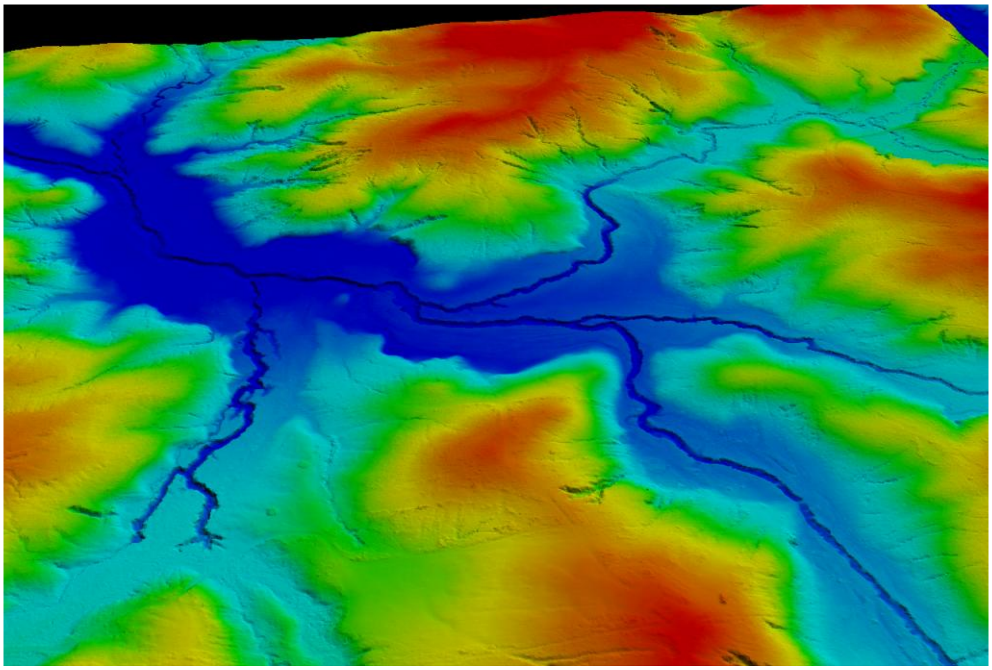

Figure 14 *– Example of excellent representation of ground in low lying area (ground elevation model).*

Artifacts

It is not uncommon for the classification algorithms to occasionally misclassify non-ground points. This misclassification results in remnants of vegetation or manmade structures known as artifacts that do not represent the bare-earth terrain. **Figure 15** shows an example of an area where some building remains were left in during the classification process. This error is very common in production datasets, but it is easy to fix and does not alter the usability of the LiDAR product.

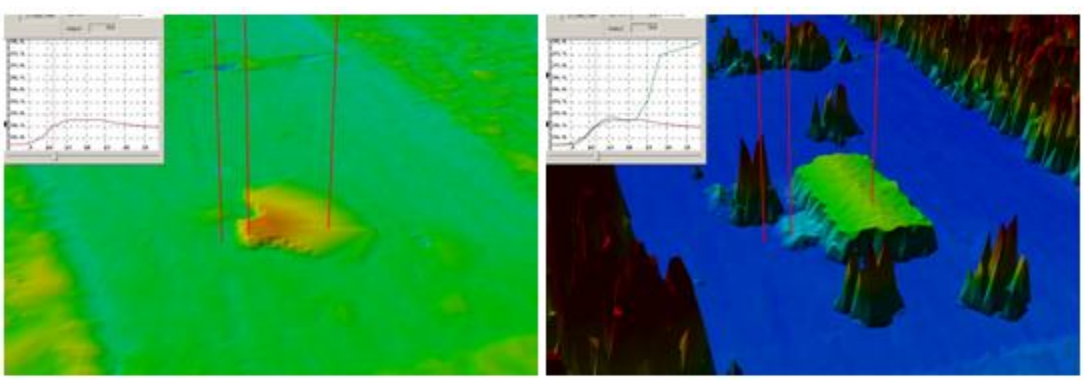

***Figure 15** – Tile 1678-01 Potential building artifact (L: bare earth model, R: full point cloud intensity model).*

Another type of artifact that was seen in the data appears to be a result of the previously mentioned intensity issue. The intensity images in a small subset of the tiles revealed high intensity values at nadir which sometimes causes what look like elevation spikes in the full point cloud. In some of these cases the classification process was not completely successful and a few of these “nadir spike” points were left in, resulting in a small false berm in the ground surface (Figure 16). Although this type of error is easily fixable, most of these elevation raises measured about 20 cm which is considered negligible.

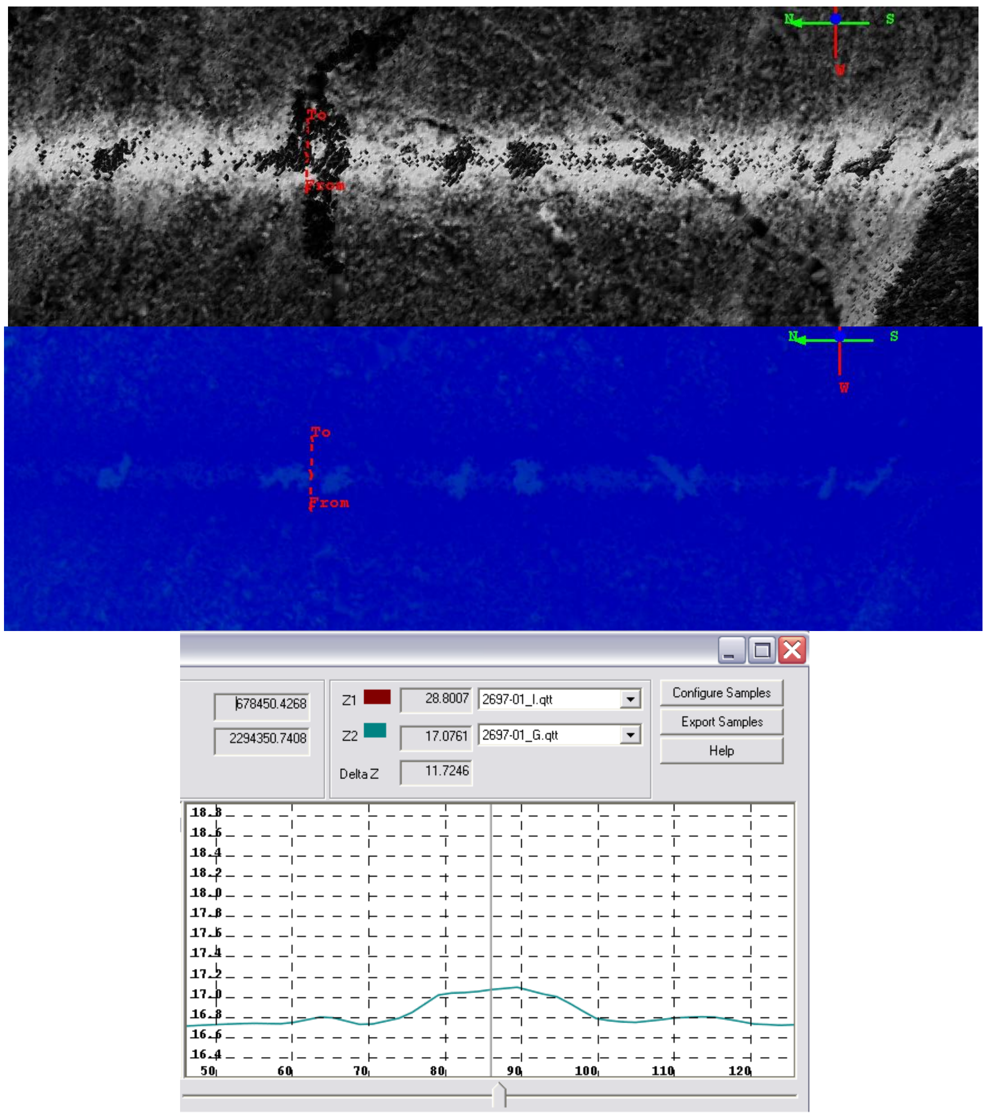

***Figure 16** – Tile 2697-01 Intensity artifacts (Top: Full point cloud intensity model, Middle: Ground surface model colored by elevation).*

Inconsistent Editing

Several instances of inconsistent editing of natural features were found in this dataset (Figure 17). Since there is no indication whether these features manmade or not, they cannot be considered to be artifacts. Another example of inconsistent editing that Dewberry found is depicted in Figure 18. In this case, it appears as though more ground points were removed from the top tile than its neighboring bottom tile. This type of error was not found to be very common in the dataset and has minimal impact on the quality of the data.

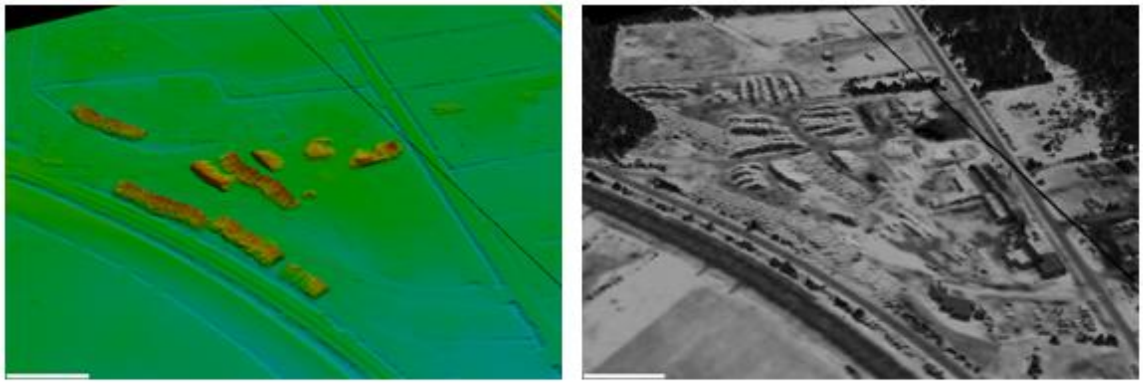

Figure 17 *– Tile 2648-01 Inconsistent Editing (L: Bare earth model, R: Full point cloud intensity model).*

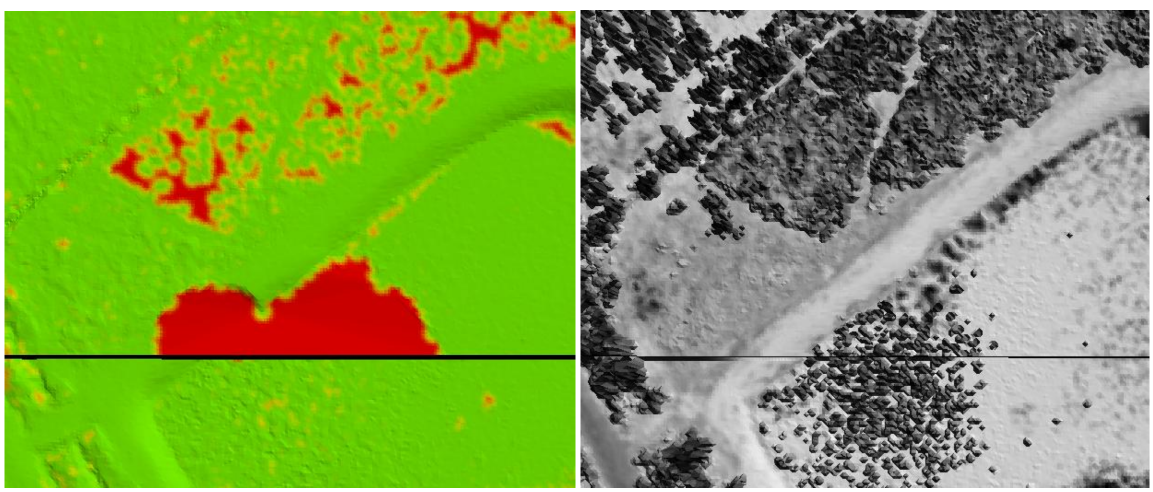

Figure 18 *- 1664-01 Inconsistent editing across tiles (L: Ground density model, R: Full point cloud intensity model).*

Misclassification

One of the more common problems seen in Clarendon County was misclassification of ground points. There was a correlation in some instances between areas having a high intensity value and those lacking ground points. This problem may have been the reason for the misclassification in Figure 19. The LAS file for this area shows that some areas, which should have been classified as ground, were moved into class 1 (unclassified). The presence of this type of error has an insignificant effect on the accuracy of the data however some redefinition of ground may be necessary for micro-level analyses on these areas.

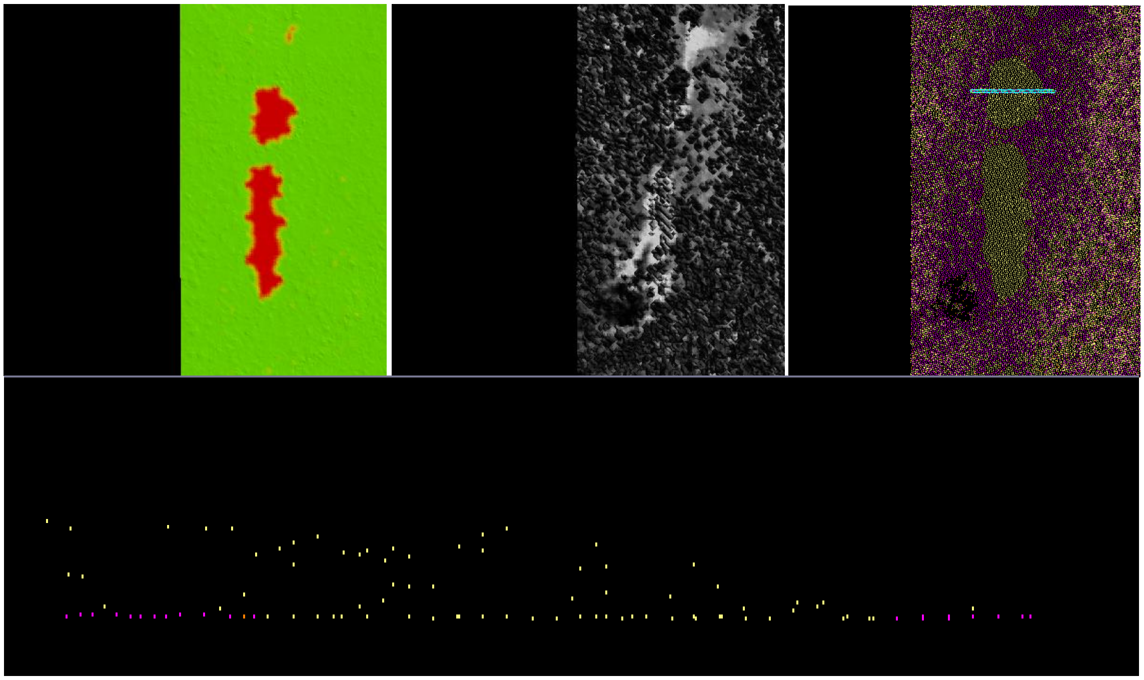

Figure 19 *- Tile 1655-01 Misclassification of ground. Top left is ground density model, middle is full point cloud with intensity. Top right is full point cloud LAS points colored by classification, yellow is unclassified (class 1) and purple is ground (class 2).*

Poor LiDAR penetration

Several areas were identified with patches of low density of ground points. This may be unavoidable. When the vegetation is very dense, the LiDAR may not penetrate the canopy all the way to the ground; this is illustrated in Figure 20. This type of sparse density of ground points was found throughout the dataset and sometimes causes the surface to be less accurate. Poor LiDAR penetration cannot be fixed without a re-flight, but even then, this might be inherent to the type of vegetation surveyed. While increasing the flight overlap would provide different angles of incidence and would increase the chance of penetrating the canopy, it is possible that the density of the vegetation prevents any point to reach the ground. Regardless, the accuracy of the data is expected to diminish in vegetated area and as soon as a few ground points are available an elevation model can be interpolated with acceptable precision especially in flat terrain.

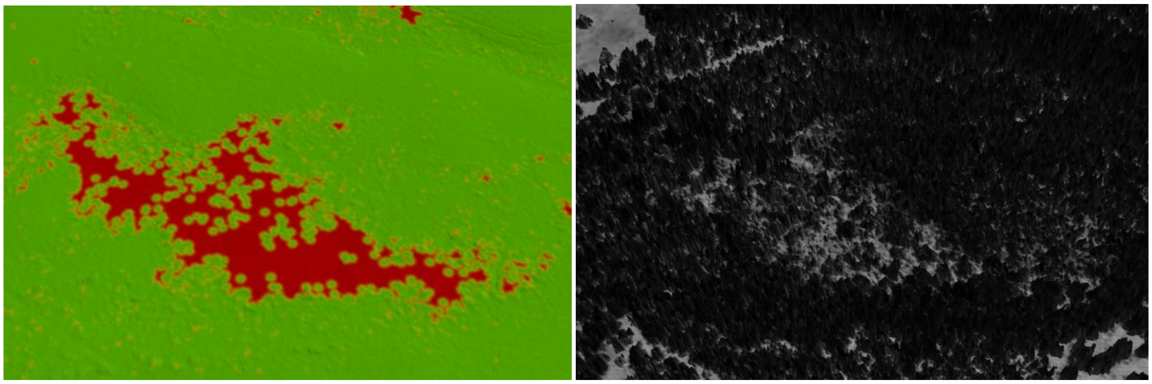

Figure 20 *– 2608-01 Poor LiDAR penetration (L: Ground density model, R: Full point cloud intensity model).*

Flight line ridges

Small ridges at seam lines caused by a vertical mismatch between two adjacent flight lines were noticed during the QA process. Small ridges at seam lines caused by a vertical mismatch between two adjacent flight lines were noticed during the QA process. Smoothing of the flight lines does not occur; therefore it is possible to find flight line ridges. Although flight line ridges found within the Clarendon data were below the commonly accepted threshold of 20 cm as shown in Figure 21.

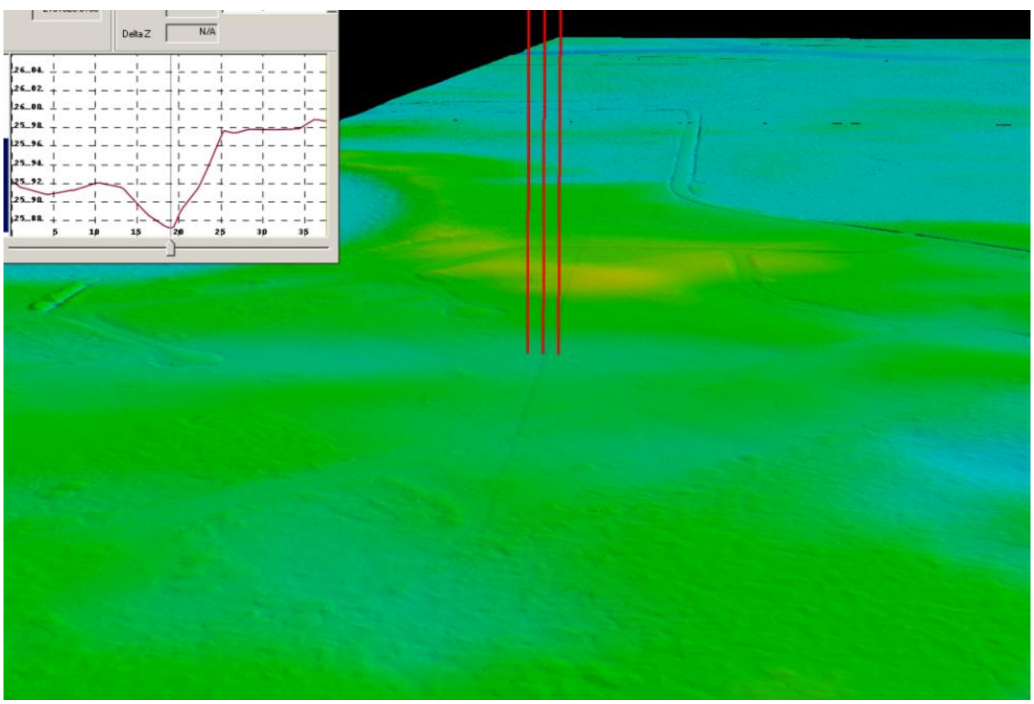

Figure 21 *– Tile 1680-01 Negligible flight line offset (bare earth model).*

Conclusion

Overall the LiDAR data meets the minimum standards for absolute and relative accuracy. The level of cleanliness for the bare-earth terrain easily meets the specifications and no major anomalies were found. The processing performed exceptionally well given the low relief of the terrain. The figures highlighted above are a sample of the minor issues that were encountered and are not representative of the majority of the data, which is of high quality. The intensity images meet specifications and the terrain and multipoint entities are correctly derived from the classified bare earth LiDAR points.

Appendix A Checkpoints

The horizontal coordinate system is South Carolina State Plane **international feet,** horizontal datum NAD83 **HARN** with **elevation in meters** (NAVD88).

The point numbering scheme uses a three digit sequence starting with the county number (SC numbers its counties in alphabetical order), a dash, followed by zone number, a dash and then a sequence number corresponding to order of collection within the zone, the land cover code was concatenated in front of the number.

pointNo	easting	northing	elevation	zLiDAR	LandCoverType	DeltaZ
o14-5-1/CYPRESS FORK RESET	2281094.604	697823.667	29.768	29.509	Open Terrain	-0.259
o14-3-8/HARBRO	2239977.324	676863.460	37.959	37.8206	Open Terrain	-0.138
o14-6-12	2297706.140	750384.718	39.637	39.5288	Open Terrain	-0.108
o14/1-1/ST PAUL	2184375.312	636406.025	29.409	29.3023	Open Terrain	-0.107
o14-2-4/CLAPORT AZ MK	2240837.214	637015.290	28.321	28.2268	Open Terrain	-0.094
o14-2-5/014 005 AZ MK	2242777.648	626565.852	30.211	30.1175	Open Terrain	-0.094
o14-3-6/MANNING	2239859.321	678262.254	38.771	38.6786	Open Terrain	-0.092
o14-6-5/PINE DALE	2311199.080	749748.599	32.676	32.6018	Open Terrain	-0.074
o14-4-1/HARVIN CIRCLE	2196977.149	692775.770	54.388	54.315	Open Terrain	-0.073
o14-2-12	2234679.668	634911.946	31.096	31.0329	Open Terrain	-0.063
o14-2-14/DAVIS STATION	2223640.810	644273.272	43.022	42.9620	Open Terrain	-0.060
o14-5-11/014 001 AZ MK	2319138.925	726289.940	29.331	29.2775	Open Terrain	-0.053
o14-2-1/CLAPORT	2241284.097	640159.581	30.094	30.0422	Open Terrain	-0.052
o14-1--4/YONDER	2180908.520	628977.554	26.514	26.4676	Open Terrain	-0.046
o14-2-3/MNI A	2240684.560	638717.626	28.848	28.8395	Open Terrain	-0.008
o14-4-11	2202863.978	688358.433	50.015	50.012	Open Terrain	-0.003
o14-6-1/REM	2302970.506	754498.810	37.927	37.9254	Open Terrain	-0.002
o14-3-1/A M NASH	2230685.226	681183.761	43.006	43.0137	Open Terrain	0.008
o14-5-2/JUNE BURN	2291811.372	704920.184	29.389	29.4025	Open Terrain	0.013
o14-3-9/CARSON RM6	2234183.040	673667.665	38.411	38.4307	Open Terrain	0.020
o14-2-7/110	2247206.126	613795.260	26.281	26.3934	Open Terrain	0.112
u14-1-6	2171353.677	631143.269	24.381	24.1771	Urban	-0.204
u14-1-9	2189483.002	633977.175	29.033	28.8979	Urban	-0.135
u14-3-7A	2239894.575	678010.280	38.287	38.1673	Urban	-0.120
u14-1-2A	2184391.275	636339.180	29.442	29.3367	Urban	-0.105
u14-1-30	2185741.483	638512.533	28.949	28.8464	Urban	-0.103
u14-5-7	2300038.704	708300.441	31.468	31.377	Urban	-0.091
u14-6-11	2298448.453	746165.922	29.593	29.508	Urban	-0.085
u14-6-4	2299896.209	751123.105	38.534	38.4667	Urban	-0.067
u14-3-28	2231868.599	671991.286	37.426	37.362	Urban	-0.064
u14-5-3	2292690.387	704727.222	29.060	29.0012	Urban	-0.059
u14-4-12	2202856.961	688633.444	49.830	49.7785	Urban	-0.051
u14-4-4	2195315.056	693889.904	55.845	55.806	Urban	-0.039
u14-3-2	2230694.129	681305.351	43.859	43.8224	Urban	-0.037
u14-3-26	2240019.603	678196.093	38.393	38.3615	Urban	-0.032
u14-3-25	2230664.259	681290.771	43.791	43.7603	Urban	-0.031
u14-4-9	2191822.673	688685.071	53.113	53.099	Urban	-0.014
u14-3-30	2230673.546	681276.117	43.762	43.7495	Urban	-0.013
u14-3-2B	2230694.150	681305.307	43.829	43.8228	Urban	-0.006
u14-6-30	2310925.461	749603.688	32.640	32.6409	Urban	0.001
u14-3-27	2240048.238	678069.573	37.784	37.7978	Urban	0.014
u14-2-31	2240813.739	638321.719	28.176	28.2068	Urban	0.031
u14-6-6A	2311156.168	749852.077	32.641	32.6745	Urban	0.034
u14-2-2	2241303.865	640552.649	30.983	31.0225	Urban	0.040

u14-2-30	2240737.173	636857.862	27.214	27.2965	Urban	0.083
u14-3-3	2230442.741	680963.604	42.513	42.66	Urban	0.147
w14-1-7	2172968.205	631787.952	27.114	27.0242	Vegetated	-0.090
b14-1-8	2184678.534	634095.109	27.179	27.0927	Vegetated	-0.086
w14-6-3	2303976.844	755180.038	37.609	37.5299	Vegetated	-0.079
h14-5-4	2295893.154	700103.336	29.698	29.619	Vegetated	-0.079
w14-2-6	2242756.023	626347.976	30.440	30.3723	Vegetated	-0.068
b14-6-9	2297587.630	749109.671	37.951	37.8957	Vegetated	-0.055
b14-6-10	2297582.930	747686.101	32.994	32.9426	Vegetated	-0.051
h14-1-5	2177920.732	633089.298	26.537	26.4857	Vegetated	-0.051
b14-4-5	2195126.206	699543.170	55.500	55.453	Vegetated	-0.047
h14-2-10	2239508.529	663347.740	37.981	37.9423	Vegetated	-0.039
b14-2-11	2238977.815	666099.989	37.769	37.7315	Vegetated	-0.038
h14-5-8	2302112.089	710307.232	29.661	29.6264	Vegetated	-0.035
h14-2-8	2243109.923	625212.933	28.255	28.2228	Vegetated	-0.032
w14-3-12	2241669.435	681201.180	35.541	35.5108	Vegetated	-0.030
w14-5-5	2296237.752	700238.047	29.242	29.2153	Vegetated	-0.027
h14-4-6	2194994.610	699410.461	55.377	55.3572	Vegetated	-0.020
b14-5-6	2289899.487	703836.420	29.181	29.1661	Vegetated	-0.015
b14-5-9	2302273.554	710277.922	29.234	29.2223	Vegetated	-0.012
w14-2-13	2235107.646	634723.776	30.284	30.2796	Vegetated	-0.004
w14-4-3	2196681.284	692774.161	54.179	54.178	Vegetated	-0.001
h14-3-10	2234222.140	673688.733	38.034	38.04	Vegetated	0.006
h14-6-8	2310354.037	755387.180	32.407	32.4164	Vegetated	0.009
h14-1-3	2184470.185	636193.676	29.441	29.4569	Vegetated	0.016
w14-2-9	2241973.899	640054.391	32.253	32.2776	Vegetated	0.025
b14-3-5	2231714.306	679250.666	40.590	40.6368	Vegetated	0.047
h14-4-8	2191757.165	686924.753	51.871	51.929	Vegetated	0.058
w14-3-4	2230610.011	679244.072	40.702	40.76	Vegetated	0.058
b14-4-7	2191751.589	686859.365	52.002	52.0602	Vegetated	0.058
h14-5-10	2314879.610	720381.906	25.573	25.6376	Vegetated	0.065
b14-3-11	2235574.300	684440.004	32.084	32.1519	Vegetated	0.068
h14-4-2	2196743.030	692843.400	54.315	54.390	Vegetated	0.075
h14-6-2	2302841.282	754715.752	37.866	37.9835	Vegetated	0.118